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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

THEORY, EXPERIMENT OF PRACTICE

By

P. L. Kapitsa

FOREIGN TECHNOLOGY DIVISION

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MOSSHTABY NAUCHNOY RABOTY I ROL' UCHENOGO-ORGANIZATORA

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THE SCOPE OF SCIENTIFIC WORK AND THE ROLE OF THE SCIENTIST-ORGANIZER

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ABSTRACT: ~~This~~ article, a 1959 speech, touches on the organization, planning and management of scientific work and scientists. The author, the editor-in-chief of the Journal of Experimental and Theoretical Physics, expresses a preference for having scientists run scientific projects, as opposed to administrative specialists. The role of the project director is compared, in importance, to that of a movie director. The need to train future directors of scientific work is emphasized. The author notes N. N. Semenov's speculation that in the future half of humanity will participate in creative scientific work.
English translation: 4 pages.

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OSVOYENIYE DOSTIZHENIY NAUKI I TEKHNIKI

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ASSIMILATING (MASTERING) THE ACHIEVEMENTS OF SCIENCE AND TECHNOLOGY

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ABSTRACT: This article, a 1965 speech, is concerned with the decrease in the growth rate of USSR labor productivity [GNP], from 13%/yr to 4-5%/yr, in recent years. The author attributes this decrease to the fact that the advancements of science and technology have not been assimilated (mastered) in and by industry. "Progress always meets resistance from the environment." The mastering of new technology by industry requires that: 1) industry should be interested in learning to do something new; 2) industry should be properly prepared to learn it; 3) the normal, routine workload of a plant or team that is assigned to implement new technology should be reduced; 4) those doing the something new should be paid more; 5) there must be a clear instructional program that considering the industrial facilities of the plant and the specific nature of what is to be familiarized; 6) those who come up with a new idea, be it process or device, should work to put it into practice. The poor relationship of scientists to industry is deplored. American expenditures on theoretical and applied science are discussed, as is the brain drain from England and Germany to the United States. The two reasons given for this brain drain are the higher salaries and, more importantly, greater freedom of American and Soviet scientists (from engineer on up) is compared (they are about equal), but it is found that Soviet scientists produce about half the scientific work that United States scientists do. United States budgetary spending on science has increased 14%/yr over the last 20 years, and in 1965 it increased 20%, Soviet funds for science in 1964 were 6.5 billion rubles, and increase of 9.9% over 1963 funds. The author states that "in the last several years the technology gap between the USSR and the United States not only did not diminish, but increased." This gap should be

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reduced by improving the organizational forms for the development of science, the material base, the quality and labor productivity of USSR scientists. English translation: 9 pages.

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ABSTRACT: This article, a 1962 speech, considers the preponderance of theoretical works in Physics and Mathematics, in particular, and Soviet science in general. In the articles submitted to the Journal of Experimental and Theoretical Physics, theoretical outway experimental by a ratio of three or four to one. The gap between theory and practice is deplored, and it is attributed to the less favorable position of applied scientists in the USSR. Also, the role of a team leader in experimental work is underevaluated, and the work is not given a sufficient material support [funds, equipment and personnel]. Suggested improvements are: establishing prizes for experimental work; bringing experimental work at least up to the level of theoretical work, in prestige and pay. English translation: 5 pages.

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ABSTRACT: This article, from Pravda, 17 June 1941, is a think piece of historical interest. The author complains of the separation of science and technology, the lack of organization in scientific work, the lack of discussion when papers are presented to the Academy of Sciences, and he desires a healthy public airing of scientific differences of opinion. Also the establishment of task forces composed of scientists from the different pertinent disciplines to tackle individual problems. English translation: 5 pages.

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ABSTRACT: This article, a 1964 speech, is concerned with increasing the productivity of Soviet scientists by improving the morale, financial support and personnel of scientific institutions. Suggested improvements are: more participation in foreign scientific conferences with delegates picked by scientific qualifications and interest, not by bureaucratic methods; the editorial selection board of journals should work directly with the authors of submitted works to improve the articles; the concentration of personnel in the more promising areas of science; institute directors should be allowed more freedom in selecting their personnel and in spending the funds allotted to the institute; the work of a director should be simplified and made more attractive to have more talented scientists to this field. He also urges greater expenditures in the amenities of life at new scientific institutes being constructed outside of Moscow to attract scientists from Moscow. English translation: 4 pages.

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QUESTIONS ABOUT THE ORGANIZATION OF SCIENTIFIC WORK

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ABSTRACT: This article, from Pravda, 4 May 1957, discusses the development of new organizational forms in answer to large complex problems (e.g., the construction of atomic-powered aircraft). The author suggests the creation of a single independent organization of scientists and engineers of various specialties, but persuing one common goal, solving the assigned problem and putting the results into practice. Such task teams should be created for a specific problem, of a scale to fit the problem and for the life of the problem; then the teams should be broken up and assigned to another problem. This approach will require greater funds, re-educating scientists towards mobility and diversity and away from stability. English translation: 4 pages.

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THE INSTITUTE OF PHYSICAL PROBLEMS

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ABSTRACT: This article, a 1943 report, discusses the organization of the Institute of Physical Problems, the problems imposed on it by WW II, a special cryogenic lab course developed at the Institute for Physics students from Moscow State University, and the Institute's plans for the post-war period. English translation: 19 pages.

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration
А а	*А а*	A, a
Б б	*Б б*	B, b
В в	*В в*	V, v
Г г	*Г г*	G, g
Д д	*Д д*	D, d
Е е	*Е е*	Ye, ye; E, e*
Ж ж	*Ж ж*	Zh, zh
З з	*З з*	Z, z
И и	*И и*	I, i
Й й	*Й й*	Y, y
К к	*К к*	K, k
Л л	*Л л*	L, l
М м	*М м*	M, m
Н н	*Н н*	N, n
О о	*О о*	O, o
П п	*П п*	P, p
Р р	*Р р*	R, r
С с	*С с*	S, s
Т т	*Т т*	T, t
У у	*У у*	U, u
Ф ф	*Ф ф*	F, f
Х х	*Х х*	Kh, kh
Ц ц	*Ц ц*	Ts, ts
Ч ч	*Ч ч*	Ch, ch
Ш ш	*Ш ш*	Sh, sh
Щ щ	*Щ щ*	Shch, shch
Ъ ъ	*Ъ ъ*	"
Ы ы	*Ы ы*	Y, y
Ь ь	*Ь ь*	'
Э э	*Э э*	E, e
Ю ю	*Ю ю*	Yu, yu
Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

THE SCOPE OF SCIENTIFIC WORK AND THE ROLE OF THE SCIENTIST-ORGANIZER[1]

During my forty years of scientific activity I have had the opportunity to observe the numerous changes that occurred in the development of science and in its problems. Looking at this period I find it difficult not to note the radical changes now occurring. In my youth people frequently spoke of "pure science," of science for the sake of science. No one says this now. Now science is considered as a necessary component part of the social system and not only useful, but also inalienable. The state pays more and more attention to science as the most important element of state life; now scientific establishments are considered equal to other branches of public service, for instance, National Education, Transportation, the Army. This was not so 30 years ago; then random factors ruled in the organization of science and its development was based on individual initiative.

Now, with the expanding scope of scientific research work in all countries state appropriations for the development of science continue to grow, both in academic scientific establishments, and also in industry. The most complicated installations of huge dimensions have been constructed: megavolt accelerators, powerful atomic reactors, satellites for space research, etc. The solution of such problems cannot be work for individuals; it is the result of collective creative work and requires the large organizational efforts and means available only to big states.

In connection with the growth of the scope of scientific work science has been divided into basic (cognitive) and applied science. I think that in many respects

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[1]From a speech at the International Symposium on the Planning of Science held in Prague in September 1959.

one should consider this division artificial and it is difficult to indicate the point where basic science ends and applied science begins. This division is connected with what kind of goal the scientist is pursuing, cognitive or applied. Therfore basic science is more concentrated in academic institutes and universities and applied in scientific research establishments in industry. This division of science is largely connected with the necessity of financing, planning and controlling scientific works.

In the work of a number of leading scientists it is difficult to trace when they pursued applied goals and when they pursued cognitive goals. For instance, all his life Langmuir worked at industrial enterprises and solved a number of important technical problems in the electric lamp industry, but it is well known that in the course of these works he made a number of fundamental investigations in electronics and vacuum physics.

Now we frequently discuss how we should organize scientific work that by its scope requires the participation of a large coordinated creative collective. Who should direct the work of such a collective, a scientist or an administrator?

Professor Bernal considers that here administrators play the decisive role and that they are necessary for organizational work on big scientific problems. I do not agree with Professor Bernal; not that such organizers are not necessary for collective work in science, this is correct, only in my opinion they should be not administrators, but scientists. I can best express my thought by resorting to a comparison with other regions of creative work, namely the theater and motion pictures.

Once the theater was only a troupe of actors and the director was an inconspicuous figure. Now, especially with the development of motion pictures in which thousands and tens of thousands of actors participate, the main role determining the success of the venture has passed to directors. In a great collective work a director is now necessary in science too. What requirements do we place before him? The main requirement is that his role should be creative and not just administrative. He should understand the meaning and target of the solutions of scientific work and correctly estimate the creative possibility of the performers, distribute the roles by talent and thus expediently allot his force so that all sides of the problem to be solved are developed harmoniously.

Since it is necessary to find unique organizational forms to organize the solution of any new scientific problem, even if the director personally does not work in science, he should be a person with great creative talent.

I do not know why the leader of such a splendid achievement in science as the launching of the first satellite is not worthy of the Nobel prize, although perhaps he personally did not perform the scientific work connected with preparation of this unique experiment. Didn't he organize it? After all, the movie directors Sergei Eisenstein and Rene Clair, who are great creative directors and who have created the most remarkable artistic films were not actors themselves. We know of cases of a great actor also being a great director; for instance, Charley Chaplin.

Thus, in science there are also cases of a great scientist being a good organizer of collective scientific work. Rutherford and Fermi were such multifaceted scientists. But this certainly is a happy exception, and not the rule. We are now, undoubtedly, entering a period in the development of science in which the organizers of science will be assigned a larger and larger role.

It seems to me that now we have to start specially educating and preparing people to be organizers of large scientific problems and to make this duty attractive, to give such people great respect and not simply call them some sort of bureaucrat-administrators. In a short report it is difficult to formulate the criteria for selecting these people and how they should be instructed and educated. They are very rare people and this app rently is one of the unique forms of human talent; therfore, they need very considerable attention and great care.

Thus, I assume that one of the problems of the future will be the training and development of this new type of scientist-organizer, whose activity and value I just described. This type of scientist-leader is now in the initial stage of development, but he will play the decisive role in the future, large-scale science.

The next problem I want considered is the scale that scientific work will attain in the future. Let us try to sort out the question of what expenditures (human, material and monetary resources) the state will allot to scientific work in the future. At present, even in the most advanced states this amount is only a small fraction of the budget. But, with each year this fraction relentlessly increases, in both socialist and capitalist countries.

Now many economists note great social phenomena in connection with the rise in technology. In industrial and agricultural production the role of physical labor continuously decreases. The press has repeatedly noted that with the growth of electric power resources, and the introduction of mechanization and automation, production will require of a person only a small part of his strength: through the energy of electric power stations this work will be accomplished by cybernetic machines and the released creative power and mental energy of people will mainly go to science and art. It is asked, what part of humanity will be occupied by science and the arts? Here we can resort to an analogy in the style of Herbert Spencer. If we compare the state organism with an animal and the weight of that part of the animal's body that performs mental work, the head, with the weight of all the remaining parts of the body that perform physical work, we will obtain an interesting result. Let us start with an antediluvian animal, for instance, the dinosaur. This animal had a small head and a gigantic body. We know that in the evolutionary development of life on earth such an animal had no future. In the struggle for existence only an individual with a head weight of approximately 5-10% of its body weight had a future.

Thus, in the evolutionary development of human society, culture will continue to grow and ever greater means will be expended on it. Here we can note that nature has given more generously to the development of man's mind as compared to his physique than the most advanced states have yet given [to science].

In one of his articles Academician N. N. Semenov wrote that in the future, by one or another means, half of humanity will participate in creative scientific labor. Thus, one half of the population of a state will carry out national-economic functions; the other half will work in institutes, design bureaus, at experimental plants, that cannot be mechanized or automated, but where an individual approach to the solution of each new problem is necessary. Professor Bernal describes the scientific and creative activity of people in the future otherwise. He assumes that each person will spend part of his time on mental creative work and the other part on productive labor. I personally favor Semenov's assumption inasmuch as people who are inclined toward creative activity will devote all their time to it. This gives people great satisfaction and makes creative labor more productive.

ASSIMILATING (MASTERING) THE ACHIEVEMENTS OF SCIENCE AND TECHNOLOGY[1]

It is well known that the basic index of progress in the national economy is the productivity of labor and this is increased mainly by assimilating the new achievements of technology and science.

When the growth of labor productivity is retarded, we must look for the cause of this in deficiencies of industry in assimilating the achievements of science and technology.

From our official statistical data one may see that in the past we have attained 13% growth/yr in labor productivity, then it declined and in recent years it fell to 4-5%.

This shows that now the process of assimilating the achievements of science and technology does not satisfy the demands of our industry.

I want to consider the causes that inhibit our assimilating the achievements of science and technology. It is known that the assimilation of the achievements of science and technology by our industry always passes slowly and with difficulty. One may see this from the word that we usually use, "implementation." We speak of the "implementation" of a new technology and the implementation of the achievements of science. In Russian the word "implementation" signifies that an advance forward occurs against the resistance of the environment. We have become so accustomed to any new achievement of science or technology encountering resistance during its assimilation, that we have long applied the word "implementation" without noticing

[1]From an address to the general meeting of the USSR Academy of Sciences of 13 December 1965.

that through this word we characterized the abnormal conditions of assimilating a new technology. When we begin to use the word "assimilation" of a new technology, we can consider that we have attained normal conditions for its development.

My many years of experience in this region shows that six conditions must be realized for successful assimilation of the achievements of science and new technology by industry.

I will enumerate them and we shall see what is necessary for them to exist in our country.

Mastering a new technology signifies that industry should learn to do what it did not do before. Consequently, mastering a new technology must be considered as a learning process and it must be conducted with the pedagogic methods we usually apply in studying anything new.

When we instruct students or pupils, this main condition is necessary: the person must want to learn. It is well known that if this desire is lacking, one cannot successfully drive knowledge into a person. Is our industry always ready to learn something new? Have we always created conditions in which industry feels that it is profitable to learn a new technology?

Obviously, for this desire to appear we must create favorable moral and material conditions. We must create conditions in which our industry and our plants would be interested to learn something new. They have to feel that this is profitable, useful, and honorable. This is condition No. 1.

Codition No. 2 is that when you teach a person something new, he must always have appropriate preparation. It is impossible to teach higher mathematics if the pupil does not know algebra and trigonometry. Therefore, when a student is taught something new, he should be sufficiently prepared. During assimilation of new technology we have frequently not considered this. I know a number of cases when the powers ordered a plan to produce new equipment and the plant was absolutely not prepared for this; in spite of all efforts they could not successfully fulfill their assignment. For instance, one good plant was assigned to manufacture special metallic vacuum Dewars. Although the plant had no experience in vacuum technology. With difficulty the plant managed this assignment, released many poor-quality Dewars and the process of mastering took several years. A factory that was prepared for this assignment could have fulfilled it faster and easier.

Thus, the second condition is sufficient preparation of the pupil.

The third condition is also well known from pedagogy: the student should not be overloaded with studies. Every plant and every branch of industry can master a definite amount of new material in a year if they have sufficient preparation and want to learn. But it frequently happens that as soon as a plant does well and starts to master anything well, it is excessively overloaded. We must remember that industry and a person have a limited ability to master new knowledge.

The fourth condition is when you teach someone something sufficiently favorable material conditions have to be created. It is impractical to instruct a person or a plant only at the expense of their internal material resources. There must always be a good material base for the problem at hand. More simply, it is necessary to give sufficient means to those who study something new.

The necessity of these four conditions is easy to grasp and they are comparatively simply realizable.

The fifth condition is less evident and much more difficult to realize: it consists of the following. From pedagogic practice it is well known that to instruct someone it is always necessary to develop a clear instructional program. Analogously, to teach industry something new, for fast and successful mastering it is necessary to have well worked program indicating the most successful way to go. But, as a rule, we pay little attention to this, frequently assimilation is allowed to go its own way and we even do not consider that we need some kind of program.

In composing such programs two conditions must be fulfilled. First, the program should consider the industrial possibilities of the plant and, second, it must consider the specific character of what is to be familiarized. Usually the factory lacks a person who could immediately do both. Therefore, when a scientist or inventor or even a scientific institute is assigned a program to compose, the specific character of production is not considered. When the plant itself composes the program, the special requirements of the new technology are not considered. In both cases an inferior program is obtained.

How do we get out of this position? Life shows us that there is a type of widely educated engineer who can embrace both sides of this program. There are now few such engineers and we should value them highly. We need these highly skilled engineers the same way we need engineer-designers; therefore they must be trained

and given the possibility of actively working on production as inovators of new technology. Ministries and central boards should have a bureau with such specialists. The task of these bureaus will be the composition of programs for mastering new technology and putting it into practice. We must assume, as a general rule, that when something new is put into production there should always be a well developed program. But this important condition of mastering a new technology we have allotted very little attention.

Finally, the sixth condition concerns the teacher. If there a pupil, there must be a teacher. It is well known that for successful instruction there have to be good friendly relations between the teacher and the pupil. Furthermore, the creator of a new technology, who transmits his work to industry, no matter what he is, scientist, inventor or the collective of a scientific institute, a design bureau, should be as interested in its successful mastering as the plant-expeditor. Are our scientists, our inventors and engineers as interested in industry assimilating their achievements as the people connected with enterprises and industry?

Let us consider only the case when the teacher is a scientist.

As is known, according to our laws a scientist working in industry on implementation does not receive material reward for this. We accept it that a scientist works with industry as a normal part of his social responsibility. This is absolutely different from the position in capitalist countries. When I lived in England and became a doctor, as scientist I entered a professional union of scientists and was obliged to sign an agreement according to which I did not have the right to freely consult with industry, even if this was not gratuitously, but below the rate set for my scientist rank. In capitalist countries this is done so that members of trade unions cannot compete with each other by price. Naturally, we have absolutely other conditions and such a measure cannot occur here.

I do not want to insist that material reward has decisive value here, but undoubtedly the incentives for scientists to work with industry must always be favorable. It is necessary that a scientist is interested in his work; we must create a situation in which his work would have wide acknowledgement of society and cooperation with industry should be considered a useful state activity. Unfortunately now, when we must deal with a ministry, this rarely seems an "amiable" relation. All this certainly does not promote the development of good relationships between

teacher and pupils,

Frequently we consider that it is sufficient to obtain an order prescribing the assimilation of such and such, and then we consider the process of "implementation" already ensured. But, from the given analysis it follows that the process of mastering a new technology cannot be considered simply as an administrative action; this process should be approached as a "pedagogic poem." Therefore, during organization of the mastering by industry of a new technology it is necessary to approach each problem individually, without a pattern, taking into account the character of the people and the character of the external conditions in each particular case. Of course, here the order basically determines the financial and personnel sides, but successfully mastering of new technology is based on good relationships between the pupils and the teacher and their common interest in success, in the fulfillment of a well developed program and this unfortunately is not always the case.

Now I want to touch another, not less important, question: does our science give sufficiently to mastering by the national economy and is the labor productivity of scientists sufficiently high? We must turn serious attention to these questions. To understand I think it is best to compare certain data on our scientific activity with that in American.

It is interesting to note that now in the United States they are seriously studying questions of the development of science in that country and its connection with industry and they publish much statistical material on this subject.

I will give certain figures of interest to us. This year the United States of America will expend on all scientific work 21 billion dollars, of which two thirds comes from the federal budget and one third from foundations and industry. From this sum 11%, or 2.5 billion dollars goes to academic science. From this it follows that the basic sum of the expenditures goes on science that directly serves the mastering by industry or as we say, goes to scientific work of applied subjects.

Further, Americans affirm that at the attained high cultural level and in the presence of free capital their industry does not have enough available reserve of science to satisfy the demand of industry in mastering new technology. In the United States industry mainly needs the development of absolutely new technical

[1]See, for instance, Scientific American, July 1965, p. 19.

directions such as television and movies once were and cybernetic machines and synthetic fibers now are. The birth of new regions of technology not only turns out to be the most profitable for capital investment, but it also has social value inasmuch as it absorbs unemployment and raises the living standards.

Americans consider that the insufficient scale of development of their science is basically a consequence of a deficiency of highly skilled scientists and engineers. They consider that scientific work could obtain even more money, but they now do not have enough very talented people, the leadership of which mainly determines the development of scientific work in the necessary direction. Therefore, in recent years they have begun to import scientists in large quantity, mainly from England and Western Germany. In the last 10 years they have imported 53,000 scientists, mainly young ones, 30,000 with engineering education, 14,000 physicists and 9,000 scientists of other specialties. This means 5000 or more people per year.

If we consider that one higher educational instituation gradu..., on the average, 500 people a year, this means that in Europe during the last 10 years at least 10 higher educational institutions gratuitously prepared scientists for America. Inasmuch as Americans took the best people, this means they took the cream of approximately 50 higher educational institutions. This agrivated Englishmen very much. The Royal Society created a special commission to clarify cause of such a great drain of scientific young people to the United States and to decide what measures to take to cease this draining of the blood of English science.

This was explained in approximately the following manner: although the English and Germans pay their leading scientists sufficient wages, Americans pay twice as much as the English and Germans. But it turns out that this is not the decisive cause for the emigration of scientists. The commission explained that not just the large pay attracts young scientists. The conditions of scientific work in America also attract them.

Americans release funds for scientific work somewhat differently from how this is done in other countries. The basic funds for science are released not by scientific establishments. Americans more readily grant money either for a definite subject or to individual outstanding scientists whose work needs support, usually leaving him the freedom of choosing the subject. Scientific establishments receive

only several percents of all the budgetary funds (apparently, not more than 2-3%). To be the independent master of his own material base is certainly very attractive for a scientist. They feel that their work can be completely ensured while their great independence and freedom of action are preserved.

Now let us compare American statistical data with our own. It is not only difficult, but almost impossible to make this comparison inasmuch as there is an essential difference between the organization and financing of science in capitalist and socialist countries. The difficulty is increased even more by the fact that, unfortunately, we still do a poor job of collecting own statistical data connected with questions of the organization of science.

Let us first compare the number of scientific workers. Americans consider that they now have, counting from the lower duties of engineers and technicians, 800 thousand persons occupied in scientific work. According to official statistical data, considering all scientists, including junior scientists, we have about 700 thousand. From these data one may see that we differ little from each other in number of scientists within the limits of the authenticity of the statistical data. This conclusion is also confirmed by data taken from a French source. They consider that for every 10 thousand persons in the population, America has highly qualified 23 scientists, the Soviet Union, 18.5 scientists of the same qualification, England, only 9.7 scientists, and the remaining countries have considerably less. Since our population is higher than that of America, these data show that the total number of highly skilled scientists for both us and the United States is identical, about 400 thousand.

To determine the labor productivity of scientists we must estimate their scientific production. Of course, this is difficult to do exactly. Americans try to do this in this way. They calculate the number of scientific articles in the leading regions of natural and technical sciences published by scientists in all languages in different countries in the main scientific journals. Judging by these American data, we find that Americans now produce 1/3 of world science. We produce 1/6 of world science, i.e., half of what they produce. All other countries produce less than we do. Thus, in scientific production we are the second country in the world. But, if we take the given figures we find that with approximately the same number of scientists we produce half of the scientific work that Americans produce.

Therefore, however discouraging this is, we should recognize that the labor productivity of our scientists is approximately half that of scientists in the United States. Moreover, we shall see from further data, in recent years the growth rate of our science has dropped somewhat. Therefore, it is time to ask: How can we create the conditions to develop our science in order to lift the labor productivity of our scientists?

The labor productivity in science is determined, first, by the amount of material possibilities open to the scientist and, second, by the amount of training and selection in the departments at scientific institutions.

Let us first consider that American budgetary expenditures on science are increasing rapidly. In the last 20 years these expenditures have grown an average of 14% a year, and this year the growth is greater, 20%; just from the federal budget the expenditures this year are 14 billion dollars.

A Pravda editorial on 17 December 1965 gave our budgetary expenditures on science. In the previous year they were 6.5 billion rubles. As compared to past year, their growth was 9.9%.

Thus, with an equal number of scientific workers we allot a considerably smaller material base to science and this certainly strongly affects the labor productivity. Because we cannot now strengthen the material base, we can only approximately half the number of new students, which will certainly improve their quality, and we must sift out the people who cannot completely justify their work against the advantages the position of scientist gives them.

Unfortunately, one cannot see other possibilities so that in the near future a whole series of insufficiently effective scientific workers can be transferred to industry where they can bring large benefit to the country. Of course, such a serious measure cannot be taken immediately. But this should be the tendency of development of our scientific establishments. It would have been possible, for instance, every year to shift 15-20% of the cadre from scientific establishments to industry and to select 7.5-10% of well prepared young people to improve the quality of the cadre and not to close the door of science to fresh forces. But one should also note that even if we decided to go this way with the laws and rights which the Academy of Sciences now gives to directors of institutes, this measure cannot be taken.

We should not fear to say that in the last several years the technology gap between our country and America not only did not diminish, but increased; we must urgently look for a way to compensate for this lag. If in the next few years we do not increase the labor productivity of our scientists we will not improve the conditions for mastering in industry the achievements of science and technology, and the problem of overtaking America certainly will not be solved. If we resolutely and skillfully use the large advantages that our socialist order gives in the organization of our science and industry, then this lag in growth will be only a temporary hitch. I deeply believe this: if we do not fear to say the truth about our deficiencies and errors and if we amicably look for ways of removing them, that we will soon recover our former record-breaking growth rate in scientific work.

We must continuously and gradually improve the organizational forms for the development of our science: improve the material base, raise the quality of the cadre and increase the labor productivity of the scientist. We, the scientists of the USSR Academy of Sciences, must devote great concern to all these questions. We are the leading scientific establishment in the country and therefore, more than anyone else, we are responsible for the development of science and the mastering of its achievements.

THEORY, EXPERIMENT AND PRACTICE[1]

I want to note the non-correspondence in the development of theoretical and experimental works and the absence of the necessary connection between theory and practive.

Of course, I will basically consider physical and mathematical sciences. It is not difficult to see that our experimental physics lags our theoretical. Let us take, for instance, the works submitted for Lenin prizes in 1962: there were many works on mathematics, on theoretical physics, but there was not even one on experimental physics. I am the editor of the Journal of Experimental and Theoretical Physics and I know very well the majority of articles we receive pertain to theoretical physics. The ratio is approximately 4:1 or 3:1. Our lag in experimental physics can also be seen by comparing our physics with foreign physics.

Let us take nuclear physics. It is well known that despite the technical equipment in this region we have fewer good experimental results. Of the large number of newly discovered particles the lion's share belongs to foreign physicists.

As for theoretical works, in both mathematics and theoretical and mathematical physics we are undoubtedly leading in many basic regions and we occupy our proper place in world science.

This is the opposite to what occurs in the United States, where experimental sciences are developed at the expense of theoretical sciences.

This was very well known about 20 years ago, when nuclear physics began to be

[1]From an address to a general meeting of the USSR Academy of Sciences, 6 February 1962.

developed in the United States and it was necessary to create an atomic weapon. To fulfill this assignment Americans had to "import" many theoretical physicists from Europe.

It is well known that when we solved the same problems in nuclear physics our theoreticians were fully prepared and sufficiently qualified to solve these problems rapidly and independently. During the last few years theoretical physics has improved in the United States and the gap has decreased.

An index of our lag in experimental sciences in that young people graduating from higher educational institutions rush to theoretical works.

This lag in experimental physics is a very serious factor that will inhibit the normal growth of our physics more and more. The gap between theory and experiment, theory and life, theory and practice, is a symptom of serious disturbances in the normal development of science. That we now have a breaking away of theoretical science from life and also insufficiently high quality of experimental works destroys the harmonious development of our science and, it seems to me that this occurs not only in physics, but also in a number of other regions in the natural sciences.

We should take the necessary measures to improve our experimental physics. For this we must first clarify the cause inhibiting the development of our experimental science and disrupting the normal connection between theoretical science and life. If we have the correct diagnosis of t e disease, the treatment will become obvious.

From the history of the development of physics it is well known that the division of physicists into theoreticians and experimenters happened quite recently. In former times, not only Newton and Huygens, but also such theoreticians as Maxwell usually checked their own theoretical conclusions themselves. Now, however, only in exceptional cases does a theoretician set up experiments to check his theories. This has a simple cause. Experimental technology has become considerably complicated. It requires great efforts during experiments. Usually this is not within the powers of one person; therefore the work is performed by a whole collective of scientists. In fact, such equipment as accelerators, liquefiers, the most complicated electronic circuits, reactors, etc., require a large staff of scientists in order to conduct an experiment. Therefore, a theoretical physicist cannot, in practive, check his own theoretical conclusions, but must rely on the "favor" of experimenters, he must wait for them to check his conclusions in practice.

From this we have the non-correspondence between the quantity of theoretical works and possibility of subjecting them to an experimental check. In fact, a theoretician frequently publishes several works in a year, let us say four, and usually a year or more is required to make the experimental check, and even a group of several persons, let us say five persons, must work on this: it is then obvious for each theoretician there should be from 20 to 30 experimenters. This, of course, is a popularized conception, but in general it gives an idea about the ratio theoreticians/experimenters necessary for science to develop.

Now the number of theoreticians and experimenters is approximately equal. As a result we find that most theoretical conclusions are not checked in practice. Theoreticians forget that their work takes on value after it is connected with life. Theory begins to feed on itself and in the best case its value is determined from methodical and aesthetic considerations.

For the harmonious development of science theory must not be detached from experience, and this can occur only when theory rests on a sufficiently large experimental base. Why do we lack this base? Why do we have so few people in experimental work and why is it badly organized? The answer to this question is simple: in our conditions the work of an experimenter is much harder and it "pays" less. This is not only because an experimenter loses a year or more when his work is a failure, while a theoretician loses two or three months. The work of an experimenter requires much greater effort, he must not only understand theory, but he should have a number of practical skills in working with instruments, there must be cooperative collective, frequently an experiment requires continuous work, day and night; all this means that the acknowledgement of an experimenter as a scientist who has attained scientific rank occurs considerably later than for a theoretical physicist.

In order to present a dissertation on work done by a collective he must separate that part which is his independent contribution this has to be confirmed by the leader of the work. It is simple to see that this condition basically contradicts the healthy spirit of collective work, when people continusously exchange their experience and ideas, help each other and replace one another. Singling out "personal property" to defend [present] a dissertation is an unnatural and inhibiting factor in the development of collective work.

All this repulses many people from experimental work.

The leader of a collective experimental group is also beset with difficult conditions. He carries the responsibility for the work, but inasmuch as he himself frequently does not participate in it, it is usually considered that his name should not be on the author's certificate [patent]. Until they grow up, young people certainly underestimate the role of the leader, even though he selects the collective, distributes the work among its members, and sifts good ideas from bad. The role of the leader is certainly exceptionally great. In contemporary conditions the leader of scientific work is like a director; although does not himself appear in a scene, he creates the performance.

Contemporary theater and motion pictures recognize the decisive value of the director in the creation of a performance or film. But while the role of the leader is usually decisive in contemporary collective scientific work, we are far from widely recognizing this; therefore, we have not created the conditions necessary for the successful work of the leader and his work is not properly organized. Therefore, it is now very difficult to attract able scientists to fill the leading posts in laboratories, to be directors of institutes. These positions are frequently filled by workers with administrative skills, without creative scientific qualifications, and as a result of this collectives begin to work poorly and this, as already mentioned, lowers the quality of scientific experimental work.

In such big regions of experimental contemporary physics as space research, plasma and nuclear physics, and accelerator development, experimental collectives become large and the role of the leader is decisive, and only his correct selection can ensure success of the work.

When a theoretician does his work, his tools are pencil and paper, but this is not necessary. Thus, when Euler went blind, he conducted his fundamental mathematical works in his mind.

But an experimenter needs a good material base: a location with all possible special equipment, a great assortment of instruments, special orders, special materials, a workshop, a trained staff of laboratory technicians, etc. The rate and success of the work are affected by the state of this material base. Ten years ago our material base was less than that of foreign countries; now it has improved considerably, but it has not attained the necessary level and it continues to inhibit the course of experimental work and makes it less attractive for the scientist.

From this one can understand why our young people aspire to theoretical scientific work, why we have such a non-correspondence between theory and experiment, and why our theory is detached from life. If we agree with the diagnosis I have given, the necessary measures to treat this disease can be found simply. We must set the experimenter and the leader of experimental works in such conditions that their work is at least as attractive as the work of a theoretician. We must adjust our organizational system of scientific work for collective work and encourage this character of the work. Such encouraging measures can be based on the material base and on morale factors.

As an example we can point to the organization of prizes for experimental work, facilitated methods of obtaining of degrees for a number of workers on the basis of the same collective dissertation, etc.

The work of leading natural scientists in introducing great contributions in the development of contemporary natural science constantly occurred with theory and experiment in close contact. Therefore, for the development of natural sciences it is usually fully sufficient that theory and practice were tightly coordinated and did not contradict each other. The harmonious development of theory and practice is absolutely necessary in all those regions of natural science where man can experimentally check a theory, put the achievements of science into practice and into life, and affect the cultural growth of the country.

As for the actual mechanism of the connection of theory and practice I would like to recall the beautiful comparison used by Kelvin. He compared theory with millstones and experimental data with the grain to be ground in these millstones. It is absolutely clear that, no matter how much it ground, a millstone could do nothing useful by itself (theory works on itself). But the quality of the flour is determined by the quality of grain and rotten grain cannot give nutritious flour. Therefore high-quality experiments are a necessary condition for both the construction of advanced theory and the production of practical results.

High-quality experiments are a necessary condition for the healthy development of our science.

THE UNITY OF SCIENCE AND TECHNOLOGY[1]

The life of a socialist state is constructed and developed on a scientific basis. Therefore, from first days of its existence Soviet power gave considerable attention and care to science. As a result we now have science that solves the most advanced and difficult problems. We have also industry which makes the finest and most complicated mechanisms. But the connection of our science and technology is still weak and this hinders our complete use of the whole rich reserve of creative forces of our country.

Only with a living and healthy unity of science and technology can they help each other: science opens new possibilities for technology and technology grasps them boldly, without compulsion. As technology expands science, on its part, is not only enriched by new technical possibilities, but its subjects are expanded and it becomes more purposeful.

Nowhere is there such soil for the widest application of science as in the USSR. Therefore we can explain the still weak unity of science and technology only because the most effective organizational forms of this connection have not been found. It is undoubtedly true that at the existing level of our science and technology, considering our present deficiencies, we could have attained considerably greater creative technical conquests. I do not think that this delay is explained only by the evident and gradually disappearing deficiencies as known the obstruction of creative cadres, bureaucracy, disorder of supply, etc. It

[1]From an article in Pravda, 17 June 1941.

seems to me that we have allotted very little attention to the more important organizational deficiencies.

Unique strategy and tactics are necessary to master nature. Here, as in battle, the most important thing is proper distribution of forces over the front and clear assignment of warriors.

It is necessary to inspire the scientific army by assigning problems and giving it a sense of the value of victories on given sections. We must even more skillfully form the combat units and give them responsible commanders. Life has shown that any influences on creative workers of science and technology are real only with the support of healthy public opinion. This is created at scientific meetings by the press. We still use this most important organizational possibility insufficiently.

As an example let us take the general meetings of the Academy of Sciences. They are well visited. At them one hears interesting reports with delight, but more frequently some professor lectures on augmentation of education, and not scientific discussions. There are almost no debates, there is no tradition to give public appraisal to separate scientific or technical problems and the works connected with them. There is not even a tendency to debate. And after all, debate do not appear by itself, it must be cultivated. For this we must preliminarily select the sharpest and most important questions, we must simultaneously select and prepare the opponents. The presiding officer should direct the debate, formulate controversial theses, and not allow the discussion to deviate from the basic questions. If a scientific report does not cause debate by its character, e.g., simply a report about a scientific discovery, in any case the meeting should hear the opinions of leading specialists so that a proper public appraisal will occur. Without debate and discussion public reports make no sense, it is simpler and cheaper to publish them.

I frequently feel as if we in scientific medium even fear debate and definite appraisals. Can this be because we still go with false pride founded on an incorrect presentation, as if a good scientist cannot err, since an "error" would discredit him. We seem to forget that "only he who does nothing does not err." After all, any scientific truth today can be augmented or modified tomorrow, since we are in a state of continuous approach to knowledge of the true nature of things. Only by surmounting error with error, by uncovering contradictions do

we obtain a closer solution to a problem. Errors are not pseudo-science. Pseudo-science is unrecognized errors. This is why error inhibits healthy scientific development.

We should also note that our press frequently avoids discussion of the controversial questions of science and technology.

The absence of a healthy public opinion on a number of question not only involves the possibility of the development of harmful and useless scientific work, but it also hinders the concentration of the best forces around the central problems.

Absence of discussions absolutely does not correspond to our general situation. All our scientific and technical achievements are the property of the whole country, and the people want not only to understand them but also evaluate them. And a just public appraisal inspires the workers and helps to create the enthusiasm that is so necessary in creative work. Every significant scientific and technical question has public value and, therefore, should be discussed and a judgement about it should be made.

The organization of the army of creative workers in our industry, it seems to me, is still less well developed than in the region science. While our scientists, nevertheless, are united in a certain collective, the creative workers of technology are so atomized in our huge industry that when a problem is assigned, they first have to be rounded up and that turns out to be very difficult.

I will now speak, not about those smaller battles that lead to a series of technical improvements, e.g., the selection of more suitable materials, the rationalization of processes, a reduction in manpower expenditures, increasing the quality of production, etc. Although such technological growth is frequently conducted by "partisan" means by enthusiast-loners, it has large value and generally goes pretty well here. The most remarkable thing with us, of course, is that we have the widest circles of technical workers, starting with workers and finishing with engineers. But I have in mind more significant battles conducted by large units, the results of which must give our country still unexperienced possibilities.

In such big battles, even with great expenditure of means and labor, during mobilization of the best creative collective of scientists and engineers working persistently with enthusiasm we cannot guarantee victory over nature. But if the battle is won, this signifies a new stage in industrial development. Achievements of such an order will help us to overcome all. There is no doubt that the

socialist order should be the best organizer of such big victories in technology. Under no conditions of capitalism can means and people be so widely mobilized for such a battle.

To use this exceptional possibility we must learn to rapidly mobilize the best creative workers in all the leading regions of technology and to coordinate their work with our scientists.

The most significant, from my observation as organizational deficiency is that we do not give proper value to questions connected with the implementation of the new conquests of technology in life, usually not counting these works to be creative. Branch research institutes and plant laboratories have created the conditions for creative work. But the last grain, the introduction of new ideas, is usually carried out by workers in the ranks, together with their current industrial assignments. But just as a good citizen is not born, and educated takes a long time, so a new idea at the basis of machines or processes is produced only as they grow in life. The successful "training" of new ideas should be entrusted not to an ordinary engineer, master or worker, but to well selected, highly skilled creative collective.

I ran into a lack of such a cadre of creative technical workers when I had to put into the line an installation for the production of liquid air and oxygen we had developed. These installations operated on new principles of liquefaction and separation and these were mastered only in the laboratory. Industry had the problem of making this installation an easily used and reliable machine.

The biggest difficulties we encountered in organizing the base for implementation and in the selection of the cadre of engineers, technicians, designers, masters, etc., capable of creative mastering of such machines. There are certainly enough such people in industry, but few people know of them. They are scattered, they are not tabulated, and they carry out the most diverse assignments. One must grope for them, and when one find them, they are difficult to get. Because there is not even an understanding of the importance of conquering new possibilities in technology our executives frequently oppose attracting of best people and creating special conditions for the implementation of test projects.

The value of a healthy base for the introduction of new achievements of technology is shown by the example of one foreign firm that organized an experimental

plant with the basic problem developing new types of machines. This plant is Brown-Boveri in Switzerland. It is in Baden near Zurich University. Using the consultation of known professors, e.g., Stodoly and others, this plant prepared very good electrical machines and turbines. But after the surrounding countries set up tariff barrier the firm was forced to construct independent plants in a number of countries, Canada, Germany, France, and others. The technical development of new machines was concentrated in Baden where the best cadres of the firm were gathered. Thus, probably one of the most advanced experimental plants appeared in Baden.

Of course, the cause of its construction do not interest us, but it is instructive for us that successes a plant can attain whose goal is basically only to create and to master new types of machines. That this plant is actually a leading one is indicated by the fact that the first economically working gas turbine was successfully developed there.

From this example, it seems to me, we can see the force that appears if the best scientific and technical creative powers are concentrated in one place and set to work on the solution definite problems.

Therefore, I think it is time to ask the question about the unification in every region of our industry of well prepared collectives of all types of creative workers. Depending upon the scale of production it is necessary that this organization include separate workshops, and in a large region, even independent plants, with specially selected cadres. In this way we will create considerably improved conditions for introduction in our industry of absolutely new directions in technology. With solicitous and flexible leadership by such collectives, they undoubtedly will open the door to technology wide for all our science and this will lead to the implementation of the boldest and most advanced ideas. Then it will be much easier to connect the scientific and technical collectives of creative workers. And this will be a large step forward to reduce the present wide boundary between theory and life. After all, this boundary exists mainly because of temporary organizational deficiencies. In fact, as we have become even more convinced, it becomes more difficult to say where science ends and its direct connection with life begins.

THE EFFICIENCY OF SCIENTIFIC WORK[1]

I want to ask this question: with what efficiency do our scientists and institutes work? Should we not direct our main efforts not to academic growth, but to improving the working conditions of existing institutes and their colleagues in ord r to raise their productivity? Perhaps we can gain more this way with the same material expenditures. How many times we can increase the labor productivity of our scientists? Of course, here we cannot give an exact answer, but I think that we still have very large possibilities here.

There are three main methods of affecting the work of scientists to raise its efficiency. For brevity, let us call them moral, financial, and cadre. Undoubtedly, the most important of them is the first. Selection of the correct direction of scientific work and its good fulfillment considerably determine how scientists relate to it. If a scientist justifiably does not agree with one or another of his colleagues on the selection of the direction of his work, he cannot fulfill his scientific responsibilities on the whole. We have to allot more attention to cultivating and supporting scientific responsibility in the academy. This is one of the most effective methods not only to raise the level of scientific work, but also to concentrate our forces on its main and more promising directions. This is essentially the present method of planning scientific work.

One of ways of public influence is discussion of problems and separate subjects at scientific meetings. We must immediately recognize that here we still work

[1]From an address at the session of the Presidium of the USSR Academy of Sciences, 4 December 1964.

poorly. More restricted conferences on special questions go well, but the broader the conference, the worse it usually goes; the pulse of the public life of scientists is very weak. Our discussions and scientific arguments have withered.

I have said many times that we need a club for scientists where we could gather and, in an unconstrained atmosphere, talk about vital questions. The most interesting conversations on the vital questions of science when I worked in England occurred at dinners in colleges. There we discussed questions immediately gripping many regions of science and this was the best method of expanding my horizons and grasping the contemporary meaning of one or another scientific direction.

It is necessary to develop public life in the academy. In the epoch of the personality cult this was difficult. But now this is again possible! For some reason we are still behind in scientific public life, although this is definitely not peculiar to our character.

An important factor of morale influence is our participation in foreign scientific conferences and other similar encounters. We still take very little part in them. Our delegations are four or five times smaller than the delegation of the United States and other countries, and frequently the delegates are selected by bureaucratic methods without strict observance of the criterion of scientific qualification and interest. We must improve this matter and not spare the means.

One more method of morale influence on scientists which we insufficiently consider is our journals. A journal should conduct appraisal-elimination work. When an article arrives it must be subjected to a qualified appraisal and the criticism should be sent to the author; in other words, the editorial board of scientific journal should work with the author. We do this at the "Journal of Experimental and Theoretical Physics," although this means more work and sometimes it is difficult, but I consider that this work carries great benefit for the direction of scientific work.

Now about the "cadre" influence on the development of science. When we in the academy conclude that we are lagging in some scientific region, we immediately ask about material support for some laboratory or even about construction of institutes, etc. But we should remember that we cannot support all regions at an equally high level; therefore, it is much more correct to concentrate our efforts

on regions where we are strong and where good scientific tradions have been formed. We should mainly develop those directions in science where we have big, bold and talented scientists. It is well known that no matter how much one aids an untalented person, he will accomplish nothing great and leading in science. Therefore, in developing one or another region our first duty is to start with the creative forces of the man working in this region. After all our science is a creative matter, just as art, or music is. Having created in a conservatory a section to write anthems or cantatas, we cannot expect to get them: if this section does not have a good composer, of Handel's class, nothing will be obtained. You will not train a lame person to run no matter how much money you spend. The same is true in science. the leadership of the Academy should find, attract and support the most talented people and this should occupy us even more than subjects.

The director should play the leading role in selecting the cadre of his institute and he himself should be a leading scientist. But he should use his great rights in this matter. In general, directors are now shackled hand and foot, in both cadre and financial questions. As I have indicated, finances are the third method of influencing the development of science. We have money for investigations, the state does not grudge it; we can get funds easier than, for example, American scientists. But you remember the children's game: "A lady sent one hundred rubles. Buy what you want," and then the addition, "Do not buy black or white, and do not say yes or no," etc. Thus, it turns out to be impossible to spend one hundred rubles without devices. A directer finds himself in that same position: he is given money but strongly limited in deciding how to spend it.

It is also known that the director is strongly limited in selecting the cadre; he cannot, by himself, dismiss anyone or, conversely, encourage anyone. The constraint of the director and his limited role in this important question is one of the causes of the low efficiency of our institutes.

Without facilitating and simplifying the work of the director of an institute as a scientist who is directing scientific work, as before it will be difficult to attract known scientists to this work. Now a number of outstanding scientific colleagues of existing institutes (for instance, our Institute of Physical Problems) are fully capable of heading independent scientific collectives, but they do not want to undertake this. If the work of a director was facilitated and simplified this certainly would promote a faster advance of able scientific young

people to management duties. Incidentally, we must note that the level of our scientific young people is higher than, let us say, in the United States, where many creative talented people go not to scientific establishments, but are attracted to industry, where the pay is considerably higher. This does not occur with us, but we do not use this advantage enough.

And last, I want to note the construction of new institutes outside the limits of Moscow. I consider this to be correct. From my experience I know that working about 50 kilometers from a large city is calmer and more productive. But to carry this out we must ensure good conditions, better than those in Moscow now, for both scientific creative work and everyday life. We do not have the latter yet. This is now the main inhibiting factor in the development of such institutes. Therefore, scientists leave Moscow very unwillingly. And here compulsion it cannot produce success.

In creating institutes outside large cities we cannot spare means on the living conditions, even if they exceed the expenditures on the institute itself.

QUESTIONS ABOUT THE ORGANIZATION OF SCIENTIFIC WORK[1]

In the development of new organizational forms of scientific and technical investigations and the implementation of their results one should consider the experience obtained in solving a number of big technical problems that appeared in connection with the stormy growth of science and technology in recent years. I feel this experience shows us that we can solve big technical problems most effectively by scientific methods succeeds when scientific research works are organized by a method other the one now considered normal. Because little has been said about these new organizational forms, and that not clearly, I shall consider them in somewhat greater detail.

First, in chronologic order I will briefly indicate the basic stages along which scientific work developed in the state scale.

The value of the influence of science on technology and the national economy was comprehended long ago. At first scientific searches were conducted in laboratories at universities or at similar higher educational institutions. Toward the end of last century scientific work had developed to such a scale that independent laboratories and research institutes had been established. We should note that in these institutes and laboratories scientific work was organized over definite regions of knowledge: physics, chemistry, biology, astronomy, etc. Then it become necessary to create scientific institutes of a more specialized character, e.g., institutes of acoustics, crystallography, optics, etc., began to be separated from physics institutes physico chemical and organic chemistry

[1]From an article in Pravda 4 May 1957.

institutes from chemistry institutes.

The necessity of creating a closer contact between science and practice was sensed in the beginning of this century, especially after the First World War. Then, in industry big metallurgical, electronics and other plants began to organize their own plant laboratories, which solved current problems connected with putting scientific and technical achievements into production. The necessity of further growth of these plant laboratories brought to big independent scientific institutes working in definite region of technology growing out of them. Abroad they are at big industrial complexes and we usually have them at ministries. We call them branch institutes.

In scientific establishments and branch institutes in any developed country there are collectives of several thousand people, the most gifted and capable. Big sums are expended on the needs of these establishments. The number and size of such institutes increase continuously. One characteristic of scientific and branch institutes is the organization of their scientific work by areas of knowledge and until recently such an organization satisfied the demands of life.

But in recent decades it has become more and more necessity to solve big scientific and technical problems embracing a number of regions of knowledge. Take, for instance, the construction of atomic-powered aircraft. For this one needs physicists, atomic scientists, thermotechnicians, aerodynamicists, designers, metallurgists, and others.

We call such problems complex. But if we analyze the problems now before science we will find that, with few exceptions, all these problems must be considered complex in onr or another measure. It is obvious that the solution of complex problem is not within the powers of one specialized institute. Usually we solved it in the following way. There is always one most interested side. It takes the initiative of leadership and organizing the work. The work is distributed in the form of separate assignments to different institutes, designing bureaus and similar establishments.

With the support of central directive organs this organizational system turns out to be possible in this country. But it is easy to see that this system is not only bulky, but it also has serious defects. Its basic deficiency is the lack of coordination of the workers, the lack of constant personal contact between them. Under such condition there is not sufficient enthusiasm and purposefulness, which

so are necessary for intense creative work.

Life suggests how we should look for a way out of this difficulty. Several examples show that in all cases in solving a complex scientific and technical problem we can create a single and independent organization consisting of scientists and engineers of various specialties, but pursuing one general target, solving the assigned scientific and technical problem and putting the results into practice, such an organization has worked successfully. As an example we can name the organization created to solve the problem of intensification of metallurgical and other processes by oxygen. True, here life itself presented a problem of such a big scale that it had to be solved by special independent organizations. But, essentially, nothing hinders us from spreading this method of organization to the solution of problems connected with questions about semiconductors, heat-resisting steels, polymers, etc.

Therefore, in parallel with the presently existing thematic scientific research institutes and design bureaus working in areas of knowledge, we must start to create task scientific and technical organizations of large and small scale. Then, every such organization will solve a fully defined, urgent problem. In structure these organizations can, if necessary, include their own scientific research institutes, laboratories, design bureaus, experimental plants, etc.

For each such organization to work successfully, it should not be considered as a constantly existing establishment, but as one created only for the time needed to solve the problem, be it several months or several years. Inasmuch as these organizations will have a temporary character, when necessary they can easily be organized in those regions where the problem is most urgent and more closely connected with vital questions.

Such a solution of scientific and technical problems will not require greater means. But the main difficulty will be the necessity of re-educating certain of our scientific and technical workers who usually like the stability of working in their scientific establishments and fearing separation from them. We must educate scientists and advanced engineers and encourage a sense of mobility. Such an organization can be graphically presented as a mobile combat unit formed from military units armed with different kinds of weapons. This unit is given definite operational assignments, after completion of which it is again reorganized in

accordance with the requirements of the next assignment.

Of course, in parallel with these task scientific organizations we must have the prior thematic institutes of the Academy of Sciences and branch institutes at big plants and central boards.

Anew, these task scientific and technical organizations reduce the load on our thematic institutes, both in unfamiliar matter and overworked cadre. This will give the institutes the possibility of concentrating on the solution of problems of great scientific value.

I think it is very probable that in the future the principle of organizing works by problems should be the basis not only of solving applied technical problems, but also of solving theoretical scientific problems, and it should affect the organization of scientific work in the Academy of Sciences. That a task organization will be effective here may be seen from the fact that now the most interesting and advanced problems in science appear when several areas of knowledge are cross-pollinated, for instance: biology with chemistry, physics or radio physics with astronomy, etc. The necessity of complex development of large scientific problems is confirmed by the example of the unification of scientific works and scientists on task subjects recently conducted in the USSR Academy of Sciences. This unification turned out to be not only possible, but easy and it gave good support to the scientific responsibilities.

THE INSTITUTE OF PHYSICAL PROBLEMS[1]

When I returned to work in the Soviet Union, the question of the organization of science in general, and of scientific work at my institute in particular, greatly interested me. I was well acquainted with how science and scientific work are organized abroad. For several years I was the director of an institute in the center of English scientific thought, Cambridge. Based on this experience I felt that the organizational forms of scientific work accepted in the West were completely inapplicable here. We had to look for our own forms for the organization of scientific work at the institute and even more so for the organization of all science.

This is caused mainly by the fact that science is assigned a special place in our socialist country. Of course, in other countries it is well known and widely accepted that science plays large role in the development of production and technology. But, in our country science is recognized as one of basic foundations of the development of production and it is assigned a guiding value in the development of our technology and the national economy. Therefore, the organization of our science should be more purposeful than in capitalist countries, where it has more of an accidental spontaneous character. Here, the connection between science and life should be closer and fuller. Questions about the organization of science are especially important for us, the workers of the Academy of Sciences of the Soviet Union.

[1]From a report at a meeting of the Presidium and responsible organizations of the USSR Academy of Sciences, 18 May 1943.

Now examining the organization of scientific work in our institute I will first try to give a picture of the general principles of organization of science from which we originated and then I will tell what we have, in reality, carried out. I shall allow myself several stipulations.

I will talk basically about the organization of an institute in peacetime. Since the institute has change its appearance during the war, since it has adjusted to wartime needs, I will say several words at the end of this report about this. But this certainly must be considered as a temporary stage in the existence of our institute. Of constant interest is the structure of the institute, what will it be in peacetime? The healthier the structure, the easier it can adjust to wartime conditions, whenever they appear.

I also want to remind to you that our institute is young: it has existed only 7-8 years. Although I arrived here already more or less a formed scientists, nonetheless it was difficult to create an institute without a school or colleagues. Therefore, the institute grew much slower than if it budded from some other institute and then developed and grew independently on this basis. Additional difficulties in the selection of the cadre were connected with peculiarities of our work pertaining to the region of strong magnetic fields and low temperatures, a region of scientific work little we developed at that time in the USSR. In the first years we were occupied in forming and instructing the basis cadre of scientific and maintenance personnel of the institute. Only after the working nucleus was formed could the institute start to grow normally and to expand.

My first question was: What should be the tasks of an institute of the Academy of Sciences? By this question I had in mind, of course, a physics institute or, in general, an institute dedicated to investigations in the region of natural sciences; the problems and organization of an institute working in other regions of knowledge will certainly be different; therefore, I previously argued against too wide a generalization of those theses which I would develop.

Further, I emphasize that we are speaking about the organization of an institute of the Academy of Sciences itself. What is the Academy of Sciences? The Academy of Sciences is the main headquarters of Soviet science. From my point of view, it must direct all our science, from top to bottom, and direct it along a healthy channel.

Each of its separate institutes should have the very same policy, i.e., to

try to have a leading influence on science in that region in which it works, to try to make its branch advanced.

Therefore, the first assignment of an institute of the Academy of Sciences is to be occupied with great science. Great science studies the basic phenomena necessary for the deepest knowledge of nature. The task of great science is to give the knowledge necessary to change nature such that is serves man in his cultural development. Therefore, the selection of the basic subjects of an institute, the selection of regions in which its work is directed is extraordinarily essential. This direction of the institute should correspond to the direction in the development of science which is the most promising at the given moment and at the given state of science, considering methodical possibilities, the one that can move forward the fastest and most fruitfully.

In physics I consider there are three such basic direction: low-temperature physics, nuclear physics and solid state physics. I cannot now substantiate why I consider these directions the most important and possibly a number of my comrade-physicists will not agree with me. Our institute studies phenomena occurring at low temperatures, near absolute zero. In the last few years this direction has been one of the most rapidly developing in physics and we can expect many new and basic discoveries in it.

Our scientific work is performed by a small number of leading scientists. This makes the work of the institute purposeful, makes it center around a small number of leading subjects. Nothing is so dangerous to the scientific work of an institute as obstruction by minor subjects that distract one from the basic problems and aspirations. The basic subjects of the institute are developed by a small number of workers, 3-4 scientists, and this makes things purposeful.

After the selection of the general direction of the work, the next important question is selection of the scientific workers. In great science significant successes can be attained only by very creatively gifted and dedicated people. There are not many such workers in science and there cannot be many, just as one country cannot have many great writers, composers or artists. But, having them, we should put them in such conditions to use their scientific forces for the development of our great science most fully and expediently. Therefore, the nucleus of an institute must unconditionally be formed only from a small quantity very thoroughly selected scientists. This nucleus should be entirely devoted to

scientific work. An institute should be organized so working conditions are created in it in which the scientists are occupied with by science in the laboratory at least 80% of their time, being distracted by other functions not more than 20% of the time. Only under these conditions can scientists sit in the laboratory and to actually work. Only when you work in the laboratory yourself, conduct experiments with your own hands, frequently even get into their actual routine part, only than can you get real results in science. You can't do good work with someone else's hands. A man who spends several tens of minutes directing scientific work cannot be a great scientists. In any case, I have not seen or heard of a great scientist who worked this way and I think this is generally impossible. I am sure that when even the biggest scientist ceased to work in the laboratory himself he not only stopped his own growth, but he also stopped being a scientist. These principles are very important, but they pertain only to peacetime: in wartime it is necessary to proceed and act otherwise.

It is especially important to instill these principles in starting scientists. For this purpose I try to put them to work in a somewhat rigid organizational framework. For instance, a scientist should not be occupied with by several subjects at once, especially when he is just beginning. When scientist has matured, become more advanced, he can manage, in rare exceptions, 2-3 subjects simultaneously, but it shoudl start with only one.

From organizational methods important for successful work we know that a scientist should work a limited number of hours. "Overtime" work is harmful, it exhausts a man and lowers his creative forces. In our institute it is accepted that all work is over after 6 o'clock p.m. A scientist should go home, consider his work, read, learn and rest. In exceptional cases, by permission of the deputy director it is possible to work to 8 o'clock p.m. Night work is allowed only by permission of the director and can be justified by the technical requirements caused by special conditions of an experiment. This is the regime in which the scientists of our institute work.

An institute that can become the center of great science, from the quality of its scientific forces and production, can, nevertheless, close on itself, become an isolated unit and not satisfy the requirements we initially gave it.

How can an institute affect the development of advanced science of the country, and how can it connect itself with other foci of scientific thought in

the country? There are several ways. Let us name the main ones.

First, it should use the advantages it should possess as an institute of the Academy of Sciences. These advantages are expensive and modern technical equipment, the selection of a strong cadre, thanks to which it can carry out certain scientific works impossible in other institutes. For example, our institute has a special installation to produce large quantities of liquid helium; this gives us exceptional possibilities to conduct experiments at low temperatures that are absent in other places. Using this, our institute gives to workers of other institutes a chance to work in the region of low temperatures, which they cannot do at their place. These works usually are not leading and sometimes they even stand aside from the basic subjects of institute.

Our comrades from other institutes usually visit us in this manner. Someone who wants to work with us is invited to our scientific meeting or seminar and reports on the experiment he wants to run. There is a discussion and if his proposal presents sound scientific interest and the author is sufficiently qualified, he is allowed to conduct the work. In order not to disrupt the basic works of the institute the number of outside works is small and usually does not exceed two or three.

More people want to work at the institute than we can accomodate. This is a good index that the institute is advanced because only then are outside scientific institutions interested in our works and want to see them.

The constant stay of workers from other scientific establishments with us has permitted us to carry out one of the forms of living connection with the external scientific world. Scientists who have left us after the termination of their work have obtained experience from the conducted work; they will acquaint their institutes with our other works and our experience will penetrate further and further into other scientific establishments of the country. Thus, through them a living contact will be established with other establishments and we, in turn, will know what is happening there. A living connection is the strongest connection. Its use is a good method of affecting the development of science in the country.

We must set the same living connection with foreign scientists in perspective. In the first years of the institute scientists came to us from abroad. But in the last few years the political situation has been so complicated that, although scientists wanted to come to us, the connection with foreign countries was

disturbed: about our connection with foreign scientists we can only speak and plan for the future. But this must be considered the normal and healthy condition of the work of any academic institute, since all science in the world is one inseparable whole. If an academic institute pretends to a leading position, it must try to attract workers not only of its own country, but also of other countries. This will be objective proof that advanced large science is conducted in institute.

There is one more region of influence on our culture and our science on the part of advanced academic institutes. This is the region of the preparation of scientific cadres.

No one, besides an institute, can prepare future cadres and it owes considerable attention to gradually grow them from young people. Therefore, post-graduate institute must be welcomed and supported as much as possible. But, here there are certain difficulties I want to consider.

The first difficulty is the selection of post graduate students. The fact is that the connection between scientific establishments and higher educational institutions is unsatisfactory in a number of cases. I consider that this is a great deficiency in our organization. The best scientists have gone to work in scientific research establishments. The leadership of higher educational institutions has remained mainly in the hands of pedagogues, of teachers, for whom research work is not the main part of their activity. We must admit that the predominant part of our professors cannot be considered the leading scientists of our country. Their requirement for students and their system of training young people are usually directed toward eliminating the most creatively strong young people. Therefore, in our higher educational institutions the creative inclinations of our young people are usually badly developed.

Assisting at post graduate examinations, I have usually observed that the college professors most highly value not the student who understands most, but the student who knows most. But the sciences need people who understand first of all. Therefore, it is very difficult to select students from higher educational institutions for post graduate work according to their grades. To correctly select promising post graduate students we must observe them for some time when they are occupied with work on which they could manifest their creative vein, their ability to think independently.

I think that the break between higher educational institutions and scientific institutes has brought about a selection of young scientific cadres that is much weaker now than it was in my time, when the main scientific work was conducted in higher educational institutions. I remember the time when Academician A. F. Ioffe directed the chair of physics at the Polytechnical Institute in Leningrad. I think it is not accidental that his group selected a whole series of starting scientists who progressed well (four of them are already academicians). Even now our higher educational institutions undoubtedly have many promising and talented young people, but the sieve with which we try to sift them for scientific work has such holes that they slip through and do not get to scientific institutes. If we want to start selecting the most talented scientists we must seriously consider how to find the form connecting our scientific institutes with higher educational institutions to find and educate the most creatively capable young people.

Therefore, we began to look for new forms of selecting post graduate students from the young people of higher educational institutions. This form of selecting for our institute was developed only in the last two or three years before the war and it is still difficult to say what results it will give. It consists of the following. Using the fact that we have liquid helium for experiments at low temperatures in quantities greater than all the cryogenic laboratories of the world taken together, we could organize a lab course through which every student of the physics department of Moscow University would pass. At first this course was organized only for the best students, but in the last two years, all physics students took this course, each performing 2-3 laboratory experiments with liquid helium. For cryogenic institutes, this is a great luxury, because in Leyden and other laboratories work with liquid helium is still not readily available even for scientists; every student of Moscow State University has the possibility of doing such works as, for example, on the properties of superconductors, studying magnetic phenomena at temperatures close to absolute zero, etc. It is natural that the University values this possibility and readily sends students to us. In the process of this course we established this system: the best students, those who showed greatest ability in the course, were marked and if they wished they could do more than the three assigned experiments. The scientists in charge of the course conversed with them, and the best were sent to converse with me. Thus we could note the most able young people, approach them

starting from the third or fourth year and follow them. Further, we invited the best of them to the Institute as trainees. In this duty they participated in research work as younger laboratory technicians, helped scientists in their experiments, made recordings, adjusted the simpler works, etc.

Selection for post graduate work was produced from the cadre of trainees, not just on the basis of examination answers, but taking into account how the candidate performed during work in the institute. Certainly, such a sampling of young scientists permits embracing a wider circle of young people and deprives the sampling of elements of chance. Our experiment was interrupted by the war. But if we had continued it, it would have been developed in this manner: having finished their post graduate work and obtained candidate degrees, these young scientists would go to other scientific establishments and spread the scientific experience of our institute. Further, we could expect that one out of ten or fifteen graduates would be so talented that he would remain in institute in the basic cadre of creative workers. Thus, the institute would grow.

This method of observing young people from the University, thoroughly and continuously checking their abilities, presents the only correct way for selecting young scientific cadres. We cannot deny this work our forces, and not only because the young scientific cadre is our future. They are our present. As you become older only young people, only your students, can save you from premature cerebral hardening. We learn from our students. Thanks to his experience, a teacher directs the work, but in the end the students instruct the teacher, they deepen his knowledge and expand his horizons. Without students a scientist usually withers rapidly as a creative entity and ceases to move forward. I never forgot the words of my teacher, Rutherford: "Kapitsa," said he, "you know, thanks to my students, I also feel young." And, as I approach old age I feel that contact with young people should be a modus vivendi protecting me from withering, ensuring the preservation interest in everything new and advanced in science. After all, conservatism in science is worse than premature death for a scientist; this is a brake for the development of science.

Now, let us turn to one more important form of the connection of scientific work of an institute with the external world, one I feel is unjustly disregarded, not only in scientific institutes, but also in the Academy of Sciences on the whole. This is the question about the propaganda of science.

We talk much about the popularization of science, implying by this its popularization for wide masses, but we have not become accustomed to think that, besides it, there is still the propaganda of science. Any large scientific achievement, any step forward in science can not only be popularized, and this, of course, is not a duty of the scientist; his duty is to propagandize science, i.e., to show his comrade scientists his meaning, to explain the role in science this achievement should play, to indicate what influence it can have on the development of scientific thought, on our philosophical opinions, on our technology, etc. The propaganda of science is not the retelling of scientific thoughts in simpler language. It is a creative process because it is not so clear and easy to present to oneself and explain others how one or another scientific achievement can effect the development of science, technology and culture on the whole. Also, we do little propagandizing of science in this meaning and it is not assigned a sufficiently honorary and important place in the work of our scientists. Unfortunately, in our institute too we do not always pay proper attention to this work. Our propagandist work has found expression in the form of separate lectures at scientific establishments, attracting people from other institutes to our scientific meetings, discussing problems with them, etc.

This form of the connection of science with life and other scientific institutes is random, accidental and unorganized with us. The result of this is a delayed influence of some regions of science on others and a delay of the penetration of scientific achievements into all forms of life of the country. We must think about the education of propagandists of science and the organization of their work. I always try to encourage the widest possible discussion of any scientific work, not to inhibit scientific arguments when they appear at scientific meetings, but, conversely, to consider it not a bad thing to provoke people a little so that they argued property. We must welcome the widest discussion of scientific works. The greater the arguments, the more contradictions appear, the sharper they are, the greatest the stimuli for healthy development of scientific thought. Following this tendency, our institute, more than other institutes, it seems, presents reports at meetings of the Physics and Mathematics Section of the Academy of Sciences.

Let us now approach one of the most important forms of the influence of scientific work on culture, its influence on the development of advanced technology

and industry.

In a socialist country what organizational forms should the influence of science on our technology and economy take? We have frequently debated this question and it is one of the sharpest. I must directly say that I cannot agree with the opinions on this question frequently expressed even by rather responsible leading comrades. I feel that we frequently vulgarize the idea of the connection of science and technology: very many consider that any scientific work should give an immediate yield to technology. These comrades judge the worth, or lack of it, of one or another investigation of a scientific institute only on the basis of the scale of what concrete help the scientific work rendered to one or another branch of industry. This is certainly incorrect. This approach is naive and leads to harmful perfunctoriness. Even a superficial study of the history of science and culture shows that any large science inevitable influences not only technology, but also the whole structure of our life. It is absolutely clear that only thanks to fundamental works and discoveries of Faraday have such absolutely new forms of implements of human culture as generators, telephones, etc., appeared. But, obviously, one should not require from Faraday that he himself made and the telephone and the generater. Faraday was not an engineer; moreover, the industry of his time was not ready to embody all his ideas in life. Bell, Simmons, Edison and other big engineers did this several decades later. There are many such examples. But, that Faraday did not embody his own ideas in technology does not minimize his brilliant discoveries of the laws and properties of an electrical current. We frequently judge the achievements of science only by its practical results and who honor the man who peeled the apple as the one who did the main work, whereas, in fact, the one who planted the apple tree produced the apple.

The connection of science with technology has many sides. When an ordinary engineer designs brakes for a carriage or calculates the strength of a structure he uses the laws of mechanics developed by Newton. When an expert on patents rejects the next "very promising" proposal for a perpetual motor, he bases his judgement on the law of conservation of energy discovered by Meyer, etc. When an engineer goes to a scientist for council, requesting him to either explain an incomprehensible phenomenon in the process of production or indicate how to calculate one or another mechanism, etc., this is also an important form of the connection of science and technology. All this occurs every day under the most

diverse circumstances in tens, even hundreds of places. But this is so ordinary that we do not talk about this, we do not feel or value this very much. Meanwhile, this form of the connection is one of mightly means of the influence of science on technology on industry. But for this influence to be left we must have large science and people called scientists who can direct it.

For instance, our military technology is comparable and in many respects even exceeds the technology of our enemies. How is this so? In the first place we have great science and scientists who influence our technology in a number of invisible ways.

To what, for instance, does our metallurgy owe its high level? Primary to the works of Chernov, all his students and the traditions of scientific approach in metallurgy they developed in the course of many years. Of course, engineers deserve great credit: they managed to perceive and extract all that was necessary from the great science created by founders of our scientific metallurgy. But without Chernov, Kurnakov and their followers, our metallurgy certainly would not have given such good steel necessary for our army's fine weapons. Without this steel our designers would be powerless to create first-class tanks.

Let us take one more example, our aviation. To what does it owe its progress. Without the works of Zhukovskiy, Chaplygin and their school it certainly could not have developed. But Chaplygin never designed an airplane or even traced a profile. He was a great mathematician like his brilliant teacher Zhukovskiy who gave us the basis of flight aerodynamics. The whole world bows to Zhukovskiy as the discoverer of the fundamental theorem at the basis of calculating the wing profile of airplanes and thanks to which the mechanism of wing lift became understandable. Should we require of Zhukovskiy that he design airplanes? His theorem is an excellent apple tree that he planted and apples will be picked from it for many centuries by all those who construct airplanes.

Of course, this influence of great science on technology should be more organized than it is with us now; it should be propagandized as I have said. We should also better organize the consulation of scientists by industry. Scientists should be more interested in the regions of technology in which their knowledge can render the biggest influence. If we can speak about the planning of science, it should consist of encouraging the development of those regions of knowledge which can render a wider effect on the development of technology at the given

moment. But we cannot require of a great scientist that he affect technology by directly putting his ideas into practice.

Let us cross over from this general speech to the concrete story on the connection of our institute with technology. At first glance it can appear that what I will say will contradict the ideas I have developed. But this contradiction is due to accidental circumstances: besides scientific work I am occupied with engineering problems. But this is an accidental circumstance that cannot be considered the rule. It seems to me that it is simplest to tell you how the institute developed its works on oxygen in industry.

In about the thirties our technical press animated by discussing a very important question about the wide application of oxygen in industry and its influence possible on contemporary technology. A series of interesting articles and accounts of our advanced engineers showed how great the influence of cheap oxygen could be on industry. Of them the intensification of ferrous metallurgy was specially attractive: a blast furnace, melting, the production of steel in an oxygen blast. Then there were questions of underground gasification, the intensification of a number of chemical processes, etc. All these tempting and interesting prospects rested in the question of obtaining cheap oxygen in large quantities. Methods were offered and discussed simultaneously. I was interested by these materials and paid attention to certain articles with evident errors. I began to delve into the various possibilities of obtaining the cheapest oxygen. On the basis of contemporary physical presentations it was possible to show that oxygen could be produced cheapest from air where it is in the free state. Further, it was possible to show, and I reported this to the Academy of Sciences, that at the contemporary level of technology the cheapest way of obtaining oxygen lies through liquefication of air and its subsequent distillation. Liquid air can be distilled into oxygen and nitrogen, just as we distill alcohol from its aqueous solution. Then, also on the basis of general scientific considerations, it was possible to show that in contemporary installations producing of liquid air the efficiency was not more than 10-15% and that the existing cycles of liquefication and rectification were very complicated. Further, it was possible to show that the best means of simplifying and reducing the cost of these processes for the production of oxygen in large quantity was rejecting the piston refrigerating machines and switching to rotary, turbine machines. It was interesting to note

that although the idea of building a refrigerating turbine was expressed in the 90's by Rayleigh, in spite of a number of attempts till now it was not successfully carried out. It was possible to theoretically show what, in all probability, were the errors of these attempts and how to avoid these errors. All this theoretical work was interesting to do and this certainly was the work of a scientist.

Having obtained these results, I told engineers and specialists about them and indicated what way I thought we should go in order to create a new technology for obtaining cheap oxygen. They told me directly that a professor dreams, all this is excessively unreal and far from their contemporary presentations. In other words, our technical thinking was not sufficiently mature to perceive these new ideas.

Essentially, as scientist I could have merely published my results and waited until technical thinking had ripened sufficiently to embrace and embody them in life. Today I know that through this theoretical research I outlined all the work that I myself had done in the last four years as an engineer and that I had assumed should have been done by our industry. I had the right to stop with this theoretical if I was not an engineer, if this did not draw my fervor as an engineer. They told me that those ideas I advanced as a scientist were unreal. I decided to take another step forward.

After one and a half or two years at the institute I constructed a machine to produce liquid air based on these new principles. The general theoretical positions expressed were justified. The machine was subjected to the expertise of a government commission. A resolution of the Economic Council obliged one plant to perceive our scientific and technical experience and to develop the matter further. I thought that at this stage I could be calm. The plant will start to develop new installations and develop them further in that same direction. I assumed that from our laboratory model, which gave all the necessary indices and thereby confirmed all the basic theoretical positions I had advanced, industry would develop a new technology for obtaining cheap oxygen. But the matter was not quite so. Although the government had given the plant rather rigid indications, nevertheless the plant did not carry them out.

Looking at what had occurred at the factory it was simple to understand the cause of the delay in developing and implementing new installations. This plant

[illegible] year, [illegible] engineers and designers who were greatly interested in our assignment. Some of them now work with me. The general relation of the plant collective to a new assignment could not be called hostile. It recognized the benefit and interest of something new, but the workers of the plant simply were not interested in it. They were concerned with daily cares and the main fulfillment of the basic plan of the plant. Of course, our installations took away many men, hindered the fulfillment of the plan and in its scale it did not play a role in the yearly output of the plant. I think I can best characterize the relation of the plant to new creative undertakings by somewhat rephrasing some lines from Faust. In reference to this case they we may say:

> We try for the highest, the best,
> Alas, worldly matters hinder us.
> And if our yearly plan will be carried out,
> We carry the greatest good to our dreams...

Our plants want to relate to new scientific achievements conscientiously, but life places them in such conditions that fulfillment of the plan is the most important thing for them. A year of work showed that under such condition there is no hope that the plant will begin to develop the problem of cheap oxygen independently.

Then we decided to change our tactics. The assignment was given to another plant where special workshops and a designing bureau were created exclusively for our installations. By a resolution of the Economic Council the selection of the cadre of these workshops and the technical leadership of this work were given to the institute.

Meanwhile, in order not to lose time the institute did the work we calculated had to performed by industry itself. From the installation for producing liquid air we went to the realization of new cycles, to building an installation for the production of liquid oxygen. We continued to check our theoretical designs and obtained liquid oxygen on turbine installations. We were interested in how many hours our installations could work continuously in factory conditions. Therefore, although the oxygen installation of institute worked properly, nevertheless we could not say beforehand that it was ready for industry.

At the new plant the matter went better than at the first one, but still it went slowly and, although we directed the workshop, our interference as an outside element did not always pass smoothly. In a year and a half we constructed several

installations and sent them to industry. It is difficult to say how the matter would have progressed since the war began and this new form of the connection with industry was finished.

Operational experience with plants taught us much. It showed that industry has creative engineers and a tendency to accept new technology. From the most first steps of our work on oxygen we encountered great help, support and interest in all our undertakings on the part of the government. We readily went onward in all our undertakings. Certainly, only thanks to this did the work move forward. What held up things? Undoubtedly, organizational factors. Our plant industrial organization is insufficiently adjusted for fast and smooth mastering of new ideas in technology. However, I have no doubt that our economic system can find and create organizational forms that would open the possibility of smooth and fast introduction and development of advanced ideas in technology and would give the possibility of the wide influence of scinece on industry. But these forms still have not been found and we must look for them.

War sharpens the need of the country for oxygen. We must roll up our sleeves, all forces must be harnessed for finishing machines of an industrial type and studying questions of strength and service life. This we did in Kazan after the institute was evacuated there. On the basis of the Kazan experience, under the leadership and jointly with the institute big industrial installations are urgently constructed and go into industrial use.

The war and the postwar national-economic problems of the country give the oxygen problem great urgency. We must act energetically in order to use all possibilities which our method of obtaining oxygen opens for our industry. I cannot enter into the details of the accepted measures; I will just say that now there is an independent central board, an industrial administration for oxygen, one of whose main problems is to develop and to introduce installations of our type. I have been assigned the leadership of this organization.

The subject of my report does not touch more specifically the problems set before the Oxygen Central Board and its associated Technical Council on the introduction and use of oxygen. I will only say that the target of the new organization is to connect large science with industry and to try using oxygen to intensify our metallurgy, chemical industry, power engineer, etc.

[illegible] we seem to find a contradiction with my basic theses, but this contradiction can be easily removed if we allow that there are two Kapitza's one is a scientist and the other an engineer. For the war the scientist must give way to the engineer. As an engineer I have concentrated my efforts to try to create an industrial organization which would adjust to receive and and introduce new scientific ideas. It is difficult to say what will come of this attempt, but in any case the circumstances of the war require the application of all forces in order to reach success.

All this, of course, does not contradict what I said in the beginning. All this follows from a simple coincidence that I can work both as a scientist and as an engineer. After all, there are cases of one person having two professions. For instance, Borodin was a chemist and a composer. But this cannot be the rule or an example. If you listen to a singer you do not require that he be his own accompanist. Therefore, from a scientist you cannot require that he watch over production and bring his own scientific works to industrial results. Certain scientists have the necessary engineering inclination and then one should certainty use this happy chance. But if this is not the case, to make a person do what he is not capable of or trained for, against his will, can only bring harm. I will give as an example, Academician N. N. Semenov. His works on chain reactions and combustion are some of the most brilliant and leading scientific works done in the Soviet Union. The combustion, explosion, and detonation theory coming from his works and from the works of his school have had colossal and recognized influence on the contemporary development of internal combustion engines, explosives and several other regions of technology. It is the same abroad, wherever combustion processes are studied the name Semenov is mentioned basic. But if Semenov himself had tried to construct an internal combustion engine or to direct its construction, he would have produced very little and his time and energy would have been detached from great science, where he was a master. We value Semenov as a great Russian scientist, as the pride of our theoretical thought and his work in theoretical chemistry will be valued for many generation. But, as engineer he was below average. And if a singer cannot be his own accompanist, why should he be'encourage to do this? Is it not better to train an accompanist separately? But, we must confess that there are few in industry occupied with developing the appropriate cadre for putting new advanced technology into practice. We must frankly say that this

is our great deficiency and we must struggle with it. But, it is no less harmful to waste our great scientists on this work.

It seems to me that this great question, the connection of science with industry, must be widely discussed to find healthy forms of this connection, so necessary for our fast cultural growth. We must avoid vulgarization in posing this question, e.g., the requirement groundlessly given to all scientists: to introduce the results of their own works themselves.

Against this I will always protest. Science, large science, always moved and will always move technical thought. In the Soviet Union we have all the possibilities to make this influence the most active. But these questions cannot be brought down to a primitive level.

The problems before the institute undoubtedly affect his structural appearance. In our institute there is a small staff of permanent scientists and also a cadre of temporary working scientists and post graduates. Only one third of the workers are permanent, the temporary workers compose two thirds. This has put a known imprint on the whole structure of the institute. Inasmuch as the temporary workers are not paid from the funds of the institute, it is natural that dimensions of our economic servicing apparatus do not correspond to accepted norms with respect to the number of permanent scientists. From a bookkeeping point of view this frequently has placed to us in the red, overdrawn, but if we carry the number of servicing personnel to all the scientists working in the institute this noncorrespondence disappears. We should also consider that the presence of temporary workers makes it necessary to have more qualified servicing personnel. If, at first, post graduates are not closely supervized, inevitably instruments and equipment will be broken before they learn to work. Visiting workers can also harm scientific equipment if experienced laboratory technicians are not assigned to them. They will also accelerate the work since they can help establish special instruments accepted for work at low temperatures, set rather complicated low-temperature thermometers, show the method of treating liquid helium, etc. Besides the staff of experienced laboratory technicians our institute also assigns highly qualified masters to prepare special equipment rapidly. We must note that nothing so inhibits, and so oppresses scientific work as slow manufacture of instruments for experiments. Therefore, the good workshop at the institute brings us much benefit. Now I will touch the question about

reconstruction of the work at the institute during the war.

The institute did not have to be reconstructed very much. The oxygen problem turned out to be urgent in wartime too. The war forced us to try to realize all the experience and knowledge accumulated in this region as soon as possible. We tried to organize our work in such a way as to transmit all our experience on oxygen to industry more rapidly so that, as far as possible it was used to struggle with our enemies. We also found that certain other regions of the institute's work had urgent value for the problems of war. Unfortunately, in a number of circumstances I cannot relate this in greater detail. Directing all the energy of its workers here, the institute had to considerably reduce the work in the directions I considered in the beginning of my report. We almost wholly concentrated our forces on the main direction, on oxygen, so that by a concerted blow we could find definite and fast results. We assumed that what scientific work was not accomplished during the war or would not give results before its end, could even be harmful if it took away from that work which is more urgent.

In conclusion I want to note that I tried to touch on only the most general and fundamental questions of the organization of scientific work. Some of them are still far from being finally solved by us. Unfortunately, we have discussed the question of the organization of science too little. Therefore, I allow that a number of our solutions can be improved considerably. But it seems to me unconditional that in the conditions of our country there are still many unexhausted possibilities for the organization of science. Even with the still imperfect organization of science which we now have our large science already has a greater influence on technology, on all our life, than we usually imagine. This influence is carried out by the traditions developed by great science and its connection through invisible threads with our life and industry. We must remember that without the large scientific tradions created by our scientists already from the time of Lomonosov we would not have good cannons, strong armor or fast aircraft, although not one of our scientists or academicians can design an airplane or fire a gun.

We still do not understand the possibilities we have in our country, the forces that give us proximity of our science with life, the possibilities we are given by the Soviet state for scientific work. We still do not know how to use the large freedom that exists in our country for the development of scientific

thought. But, in addition to all this, our achievements are fully real.

We are called upon to do much in a great country and we ourselves first have to value this matter, to respect and to care for its development.